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Coulomb Excitation of the 4_1^+ States of $^{194,196,198}Pt$

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Abstract

Probabilities for the Coulomb excitation of the 4_1^+ states of $^{194,196,198}Pt$ by the backscattering of ^4He, ^{12}C and ^{16}O ions are reported. Model-independent values of the matrix elements $\langle 0_1^+ \| M(E4) \| 4_1^+ \rangle$ and $\langle 2_1^+ \| M(E2) \| 4_1^+ \rangle$ are extracted. Agreement with previous measurements of these matrix elements is good. Values of β_2 and β_4 are determined for ^{194}Pt and compared with calculations of these quantities.

1. Introduction

It is now well established that the collective behaviour of atomic nuclei other than doubly-magic nuclei is dominated by quadrupole effects. Much interest therefore attaches to the question of the extent of the influence of higher multipolarities. Octupole modes are readily identified because of the opposite parity of the states involved, but the very strength of the quadrupole collectivity complicates the identification of hexadecapole effects. For example, the rotation–vibration model of Faessler *et al.* (1965) does not contain hexadecapole degrees of freedom, yet it predicts appreciable E4 matrix elements arising from second-order quadrupole effects. It is known from the work of Baker *et al.* (1976, 1978; personal communication 1986) that the sign of the product

$$P_3(4_1^+) = \langle 0_1^+ \| M(E4) \| 4_1^+ \rangle \langle 0_1^+ \| M(E2) \| 2_1^+ \rangle \langle 2_1^+ \| M(E2) \| 4_1^+ \rangle \qquad (1)$$

for the isotopes $^{192,194,196,198}Pt$ is opposite to that predicted by the rotation–vibration model. This indicates that hexadecapole effects are present. However, the magnitude of $P_3(4_1^+)$ has not been determined in a model-independent manner.

In this paper, we report measurements of the Coulomb-excitation probability of the 4_1^+ states of $^{194,196,198}Pt$ by the backscattering of ^4He, ^{12}C and ^{16}O ions. In the case of ^{194}Pt, the data enable a value of $\langle 0_1^+ \| M(E4) \| 4_1^+ \rangle$ to be extracted; in the other two cases, limits are obtained. The excitation of a 4_1^+ state can be thought of as occurring either directly or in two steps via the 2_1^+ state. There is also a contribution from the interference between these two processes. In heavy-ion scattering, the excitation probability is dominated by the two-step process, but in ^4He scattering the direct excitation can be measurable, depending on the details of the particular case. This method of measuring E4 matrix elements has been used extensively in the rare-earth and actinide regions of the periodic table (Diamond 1973).

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2. Experimental Procedure and Data Analysis

Targets enriched in a particular isotope of platinum were bombarded by beams of ^{4}He, ^{12}C and ^{16}O ions obtained from the 14UD accelerator at the ANU. Spectra of ions scattered through 174·8° were recorded by an annular silicon surface-barrier detector and, in the case of ^{4}He ions on targets enriched in ^{196}Pt, spectra of ions scattered through 90° were also recorded using an Enge split-pole spectrometer. Details of the experimental procedures and the analysis of the resulting spectra were given by Gyapong *et al.* (1986) and references therein. The spectra displayed by Gyapong *et al.* (1986) show that both the 2_2^+ and 4_1^+ states are reasonably strongly excited. However, the peaks corresponding to the excitation of the 2_2^+ states were not sufficiently well resolved to provide more than confirmation, within relatively large uncertainties, of previously measured $B(\mathrm{E2})$ values. On the other hand, the excitation probabilities of the 4_1^+ states are sufficiently precise to provide new information on

Table 1. Measured probabilities $P_{\rm exp}(4_1^+)$ for excitation of the 4_1^+ states of various platinum isotopes by scattering of the indicated projectiles through 174·8°

Bombarding energies E have been corrected for effects of target thickness

E (MeV)	$10^3 P_{\rm exp}(4_1^+)$	E (MeV)	$10^3 P_{\rm exp}(4_1^+)$	E (MeV)	$10^3 P_{\rm exp}(4_1^+)$
^{4}He on ^{194}Pt		^{12}C on ^{194}Pt		^{16}O on ^{194}Pt	
14·199	0·062(12)	40·999	2·16(11)	54·998	6·6 (1·4)
14·399	0·084(16)	41·999	2·57(11)	55·998	7·2 (9)
14·599	0·078(16)	42·999	3·11(15)	56·998	7·1 (1·1)
14·799	0·060(16)	43·999	3·51(14)	57·998	7·0 (1·2)
14·999	0·083(17)	44·999	4·06(14)	58·998	9·7 (8)
15·199	0·066(16)	45·999	4·82(17)	59·998	8·7 (7)
15·599	0·074(17)	47·999	6·0 (3)	60·998	10·0 (8)
		49·999	8·9 (5)	62·998	12·4(1·0)
^{4}He on ^{196}Pt					
14·199	0·038(10)	^{12}C on ^{196}Pt		^{16}O on ^{196}Pt	
14·399	0·039(12)	40·985	1·72(13)	54·993	3·9(3)
14·599	0·029(11)	40·997	1·38(11)	55·993	5·0(3)
14·799	0·037(13)	41·986	1·56(13)	56·994	5·2(4)
14·999	0·040(12)	41·997	1·74(11)	57·994	6·1(3)
15·199	0·070(14)	42·987	2·27(17)	58·994	7·5(4)
15·399	0·080(15)	42·997	2·00(11)	59·994	7·8(4)
15·599	0·062(17)	43·988	2·39(19)	60·994	8·7(4)
		43·998	2·51(11)		
^{4}He on ^{198}Pt		44·989	3·11(18)	^{16}O on ^{198}Pt	
15·599	0·025(12)	45·990	3·51(20)	56·997	2·3(4)
		46·991	3·52(22)	57·998	2·6(3)
^{12}C on ^{198}Pt		47·991	4·58(21)	58·998	2·9(3)
40·998	0·46 (10)	48·992	5·19(24)	59·998	3·7(4)
41·998	0·89 (13)	49·992	5·82(26)	60·998	3·6(4)
42·998	0·94 (9)	51·993	7·20(29)	61·998	5·2(5)
43·998	0·91 (10)	53·995	8·0 (3)	62·998	6·5(4)
44·998	1·43 (12)	55·996	7·3 (4)		
45·998	1·49 (14)				
47·998	2·30 (19)				
49·998	3·00 (22)				

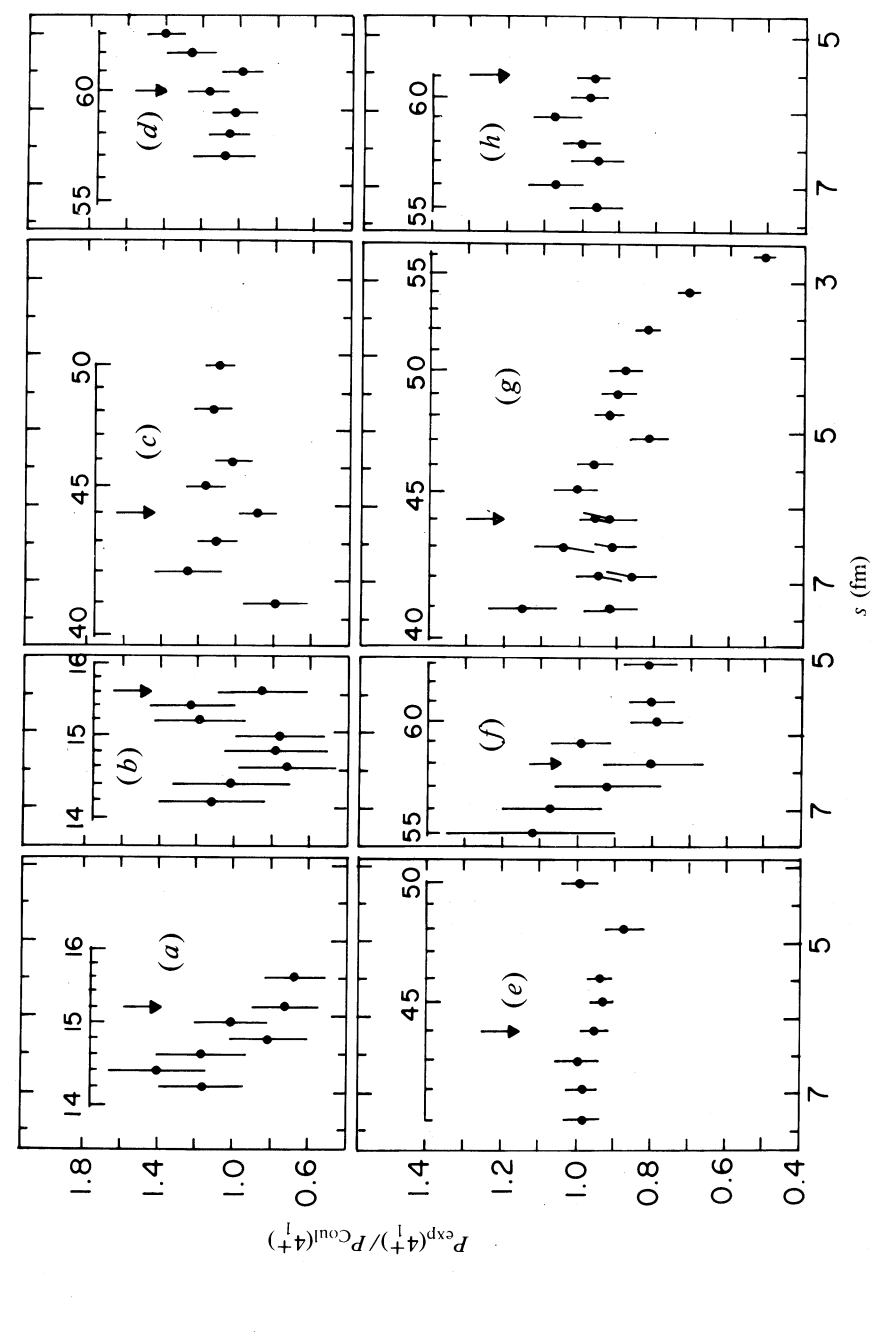

Fig. 1. Safe-energy plots for the excitation of the 4_1^+ state of ^{194}Pt [(*a*), (*e*) and (*f*)], ^{196}Pt [(*b*), (*g*) and (*h*)] and ^{198}Pt [(*c*) and (*d*)] by the backscattering of ^{4}He [(*a*) and (*b*)], ^{12}C [(*c*), (*e*) and (*g*)] and ^{16}O [(*d*), (*f*) and (*h*)] ions. The inserted horizontal scales for each diagram show bombarding energies in MeV.

the E4 matrix elements. These excitation probabilities are listed in Table 1. The excitation probability P is defined as

$$P(4_1^+) = \sigma(4_1^+)/\{\sigma(0_1^+)+\sigma(2_1^+)+\sigma(4_1^+)\}, \tag{2}$$

where $\sigma(J_n^\pi)$ is the cross section for scattering to the state J_n^π. Omitted from Table 1 are results for the scattering of ^{4}He from ^{196}Pt through 90°, since there was no evidence for the excitation of the 4_1^+ state. This is consistent with the expected excitation probabilities and the levels of background. A similar situation occurred in the scattering of ^{4}He through 174·8° from ^{198}Pt, for which an excitation probability could be obtained at the highest bombarding energy (15·599 MeV) only.

The effects of the nuclear potential must be negligible for the interpretation of these excitation probabilities with Coulomb-excitation theory to be valid. This is checked by examining the ratio $P_{\text{exp}}(4_1^+)/P_{\text{Coul}}(4_1^+)$ for deviations from unity. The quantity $P_{\text{Coul}}(4_1^+)$ is the excitation probability calculated using Coulomb-excitation theory as described below. Fig. 1 shows plots of the above-mentioned ratio as a function of s, the distance of closest approach of the nuclear surfaces, the definition of which was given by Gyapong *et al.* (1986). The bombarding energies involved are also indicated in Fig. 1. The onset of Coulomb–nuclear interference is indicated, in the present cases, by the ratio $P_{\text{exp}}(4_1^+)/P_{\text{Coul}}(4_1^+)$ falling below unity as s is decreased. The maximum bombarding energies, or minimum values of s, which we consider to be safe (i.e. free from Coulomb–nuclear interference) are indicated in Fig. 1 by arrows. Only data taken at values of s which were larger than or equal to the safe values were used in the subsequent analysis. In all cases, the minimum safe s values adopted are not less than those adopted by Gyapong *et al.* (1986) in the analysis of the excitation probabilities of the first excited states. It is, of course, not necessarily the case that the onset of Coulomb–nuclear interference will occur at the same value of s for different excited states, nor that it will always be marked by a fall of $P_{\text{exp}}/P_{\text{Coul}}$ below unity (e.g. Guidry *et al.* 1978).

The calculation of $P_{\text{Coul}}(4_1^+)$ requires, as well as the correct values of the matrix elements connecting the 4_1^+ state and the ground and first excited states, matrix elements to higher excited states. The values used are given in Tables 4 and 5 of Gyapong *et al.* (1986). The only addition to these matrix elements was the value of $2\cdot8\pm0\cdot07$ for $\langle 4_1^+ \| M(\text{E2}) \| 4_2^+ \rangle$ of ^{194}Pt (Baktash *et al.* 1978). One might also expect that the matrix elements $\langle 2_2^+ \| M(\text{E2}) \| 4_1^+ \rangle$ and $\langle 4_1^+ \| M(\text{E2}) \| 4_1^+ \rangle$ may be important. The latter is related to the quadrupole moment $Q(4_1^+)$ of the 4_1^+ state by

$$Q(4_1^+) = 88(77\pi)^{\frac{1}{2}} \langle 4_1^+ \| M(\text{E2}) \| 4_1^+ \rangle /15. \tag{3}$$

Unfortunately, with the exception of $Q(4_1^+)$ for ^{194}Pt, there are no measured values for these matrix elements. The consequences of not knowing these are discussed in the next section.

3. Results

The Nucleus ^{194}Pt

Fig. 2 shows the loci of values of $\langle 0_1^+ \| M(\text{E4}) \| 4_1^+ \rangle$ and $\langle 2_1^+ \| M(\text{E2}) \| 4_1^+ \rangle$ which are consistent with the ^{4}He, ^{12}C and ^{16}O data. Fig. 2*a* is plotted assuming both

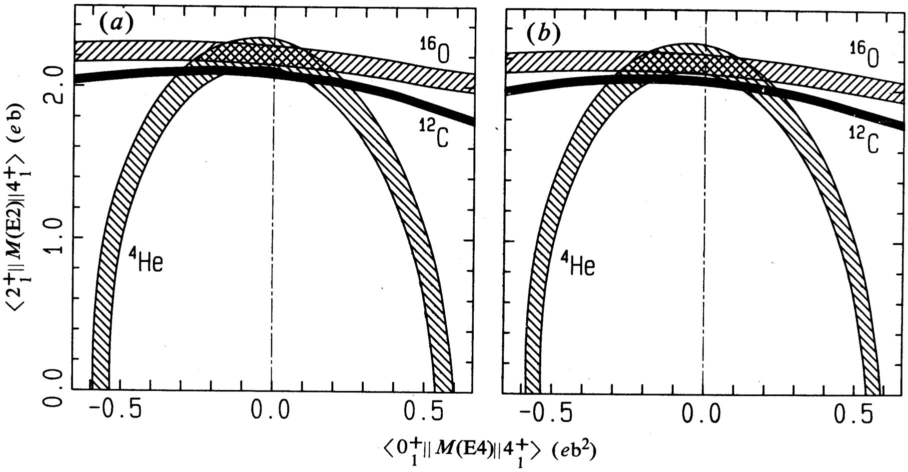

Fig. 2. Loci of values of $\langle 0_1^+ \| M(\mathrm{E4}) \| 4_1^+ \rangle$ and $\langle 2_1^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle$ consistent with the measured excitation probabilities of the 4_1^+ state of ^{194}Pt under ^{4}He, ^{12}C and ^{16}O bombardment assuming $\langle 2_2^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle = 0$, and (*a*) $Q(4_1^+) = 0$ and (*b*) $Q(4_1^+) = 0{\cdot}8$ eb.

Table 2. Values of $\langle 0_1^+ \| M(\mathrm{E4}) \| 4_1^+ \rangle$ and $\langle 2_1^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle$ of ^{194}Pt obtained with the indicated assumptions

Uncertainties due to statistics and to uncertainties in spectrum analysis are $\pm 0{\cdot}07$ eb^2 on $\langle 0_1^+ \| M(\mathrm{E4}) \| 4_1^+ \rangle$ and $\pm 0{\cdot}023$ eb on $\langle 2_1^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle$. The phase convention of Alder and Winther (1971, 1975) is used in the definition of matrix elements. This convention omits the factor i^λ which sometimes occurs elsewhere

Assumptions		$\langle 0_1^+ \| M(\mathrm{E4}) \| 4_1^+ \rangle$ (eb^2)	$\langle 2_1^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle$ (eb)
$\langle 2_2^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle = 0$	$Q(4_1^+) = 0$	$-0{\cdot}23$	$2{\cdot}143$
$\langle 2_2^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle = 0$	$Q(4_1^+) = 0{\cdot}8$ eb	$-0{\cdot}27$	$2{\cdot}076$
$\langle 2_2^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle = 0{\cdot}5$ eb	$Q(4_1^+) = 0$	$-0{\cdot}23$	$2{\cdot}102$

$Q(4_1^+)$ and $\langle 2_2^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle$ are zero. (These assumptions are discussed below.) It can be seen that the results from the ^{16}O data are not quite consistent with those from the ^{12}C data. The inconsistency is such that it could be explained by a positive value of $Q(4_1^+)$. Baktash *et al.* (1978) quoted a value of $0{\cdot}8 \pm 1{\cdot}6$ eb for $Q(4_1^+)$. Using this value, one obtains Fig. 2*b*. The discrepancy is somewhat reduced, but not eliminated, suggesting that $Q(4_1^+)$ may be a good deal larger than $0{\cdot}8$ eb. The quality of the data is, however, insufficient for a precise extraction of $Q(4_1^+)$.

If the ^{16}O and ^{12}C data are averaged, then the resulting loci of matrix elements are close to those shown for ^{12}C alone in Fig. 2. The values of $\langle 0_1^+ \| M(\mathrm{E4}) \| 4_1^+ \rangle$ and $\langle 2_1^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle$ obtained from the two situations shown in Fig. 2 are given in Table 2, together with values obtained with a nonzero value of $\langle 2_2^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle$. The solution giving the correct sign of $P_3(4_1^+)$ has been chosen, and the convention that $\langle 0_1^+ \| M(\mathrm{E2}) \| 2_1^+ \rangle$ is positive has been adopted. The value of $\langle 2_2^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle$ used to obtain the last line of Table 2 is based on simple theoretical predictions, since there are no measurements of this quantity. The theoretical predictions have a wide spread. The strict O(6) limit of the interacting boson model predicts $\langle 2_2^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle = 0$, whereas the U(5) limit of this model predicts (Arima and Iachello 1976)

$$\langle 2_2^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle = 12(5)^{\frac{1}{2}} \langle 2_1^+ \| M(\mathrm{E2}) \| 2_1^+ \rangle / 7\,, \tag{4}$$

which equals $+0 \cdot 49$ eb using the measured value of $Q(2_1^+)$ (Gyapong *et al.* 1986). On the other hand, the rotation–vibration model predicts the opposite sign; applying the model as described by Faessler *et al.* (1965) gives $\langle 2_2^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle = -0 \cdot 14$ eb. In view of the uncertainty over the value of these matrix elements, we adopt the values in Table 2 corresponding to both $\langle 2_2^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle$ and $Q(4_1^+)$ being zero, and add in quadrature uncertainties corresponding to $|\langle 2_2^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle| < 0 \cdot 5$ eb and $|Q(4_1^+)| < 1 \cdot 0$ eb. The results are shown in Table 3.

Table 3. Results of the present work

Nucleus	$\langle 2_1^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle$ (eb)	$\langle 0_1^+ \| M(\mathrm{E4}) \| 4_1^+ \rangle$ (eb^2)
^{194}Pt	2·14 (10)	−0·23 (9)
^{196}Pt	2·07 (7)	−0·11 (11)
^{198}Pt	1·61 (7)	−0·09 (9)

The Nuclei ^{196}Pt and ^{198}Pt

The loci of matrix elements consistent with the measured excitation probabilities are shown in Fig. 3. The results for ^{196}Pt show similar features to those for ^{194}Pt. However, as can be seen in Fig. 3*a*, it is not possible to exclude very small values of $\langle 0_1^+ \| M(\mathrm{E4}) \| 4_1^+ \rangle$ if $Q(4_1^+)$ is taken to be zero. Hence, contrary to the result quoted in Table 4 of Gyapong *et al.* (1986), it is only possible to obtain an upper limit on the magnitude of $\langle 0_1^+ \| M(\mathrm{E4}) \| 4_1^+ \rangle$ as shown in Table 3. The effects of this on the analysis presented by Gyapong *et al.* (1986) are insignificant. The possible effects of $Q(4_1^+)$ and $\langle 2_2^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle$ are treated in the same way as for ^{194}Pt.

As Fig. 3*c* shows, the very large uncertainty on the ^{4}He data for ^{198}Pt means that only an upper limit on the magnitude of $\langle 0_1^+ \| M(\mathrm{E4}) \| 4_1^+ \rangle$ can be obtained for this nucleus. Once again, the results shown in Table 3 include effects of uncertainties in $Q(4_1^+)$ and $\langle 2_2^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle$.

4. Discussion

Table 4 compares values of $\langle 0_1^+ \| M(\mathrm{E4}) \| 4_1^+ \rangle$ measured in other experiments with the results of our work. There is broad agreement. However, with the exception of the very precise result of Borghols *et al.* (1985), the previous results were all obtained from model-dependent analyses. Table 5 presents a similar comparison for values of $\langle 2_1^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle$. Again there is good agreement, except perhaps for ^{196}Pt for which our value is higher than previous results. This may be due to the assumption that $Q(4_1^+)$ equals zero, and hence may indicate a positive quadrupole moment for the 4_1^+ state of this nucleus.

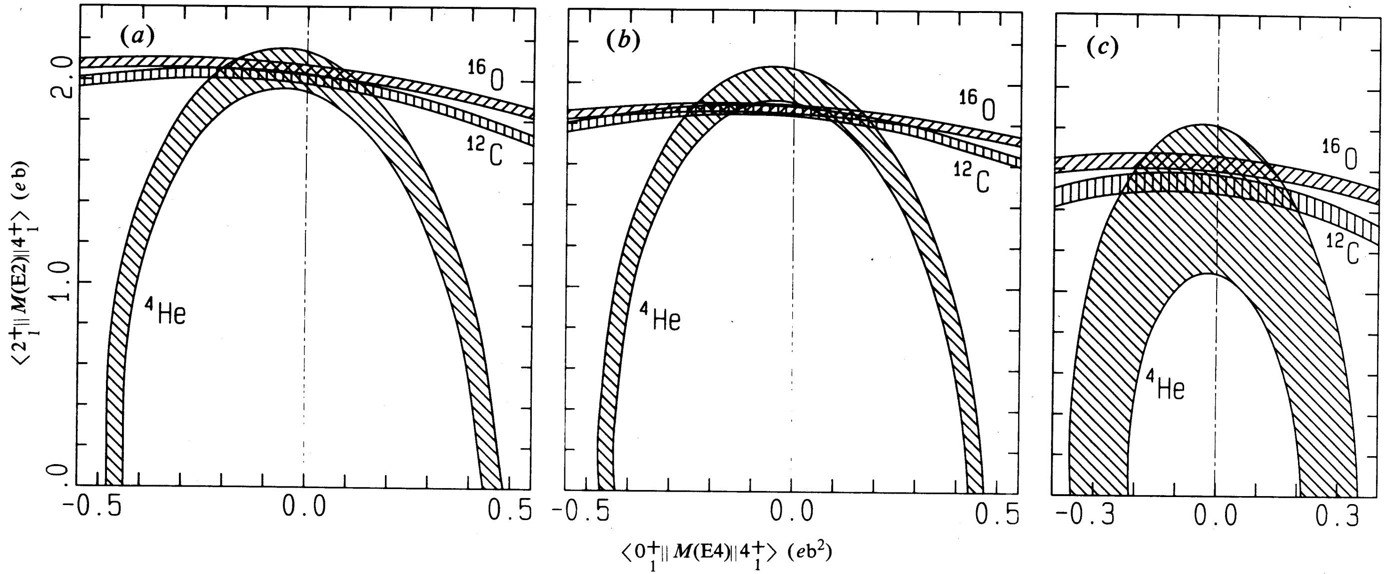

Fig. 3. Same as Fig. 2: (*a*) for ^{196}Pt assuming $Q(4_1^+) = 0$, (*b*) for ^{196}Pt assuming $Q(4_1^+) = 2{\cdot}5\ e$b and (*c*) for ^{198}Pt assuming $Q(4_1^+) = 0$.

Table 4. Results of measurements of $\langle 0_1^+ \| M(\mathrm{E4}) \| 4_1^+ \rangle$ for ^{194,196,198}Pt

$\langle 0_1^+ \| M(\mathrm{E4}) \| 4_1^+ \rangle$ (eb^2)	Technique	Reference
	^{194}Pt	
−0·096	Coul. nuc. interf.	Baker *et al.* (1976)
−0·1486	Coul. nuc. interf.	Baker *et al.* (1979)
−0·16	Coul. nuc. interf.	Deason *et al.* (1981)
−0·23(9)	Coulomb excitation	Present work
	^{196}Pt	
−0·084	Coul. nuc. interf.	Baker *et al.* (1976)
−0·203	Coul. nuc. interf.	Deason *et al.* (1981)
−0·155(16)	Inel. e$^-$ scattering	Borghols *et al.* (1985)
−0·11(11)	Coulomb excitation	Present work
	^{198}Pt	
−0·121	Coul. nuc. interf.	Baker *et al.* (1976)
−0·176	Coul. nuc. interf.	Deason *et al.* (1981)
−0·09(9)	Coulomb excitation	Present work

Table 5. Results of measurements of $\langle 2_1^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle$ for ^{194,196,198}Pt

$\langle 2_1^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle$ (eb)	Technique	Reference
	^{194}Pt	
2·07(16)	Coulomb excitation	Milner *et al.* (1971)
2·26(6)	Recoil distance	Johnson *et al.* (1977)
2·06(7)	Coulomb excitation	Stelzer *et al.* (1977)
2·01(5)	Coulomb excitation	Baktash *et al.* (1978)
1·986	Coul. nuc. interf.	Baker *et al.* (1979)
2·14(10)	Coulomb excitation	Present work
	^{196}Pt	
1·83(15)	Coulomb excitation	Milner *et al.* (1971)
1·90(8)	Recoil distance	Bolotin *et al.* (1981)
2·07(7)	Coulomb excitation	Present work
	^{198}Pt	
1·56(7)	Recoil distance	Bolotin *et al.* (1981)
1·61(7)	Coulomb excitation	Present work

Although, as indicated in Section 3, our data are unable to provide useful values for $Q(4_1^+)$ simultaneously with $\langle 0_1^+ \| M(\mathrm{E4}) \| 4_1^+ \rangle$ and $\langle 2_1^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle$, the adoption of the previous values of $\langle 2_1^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle$ shown in Table 5 allows $Q(4_1^+)$ to be extracted. We have used the values 2·10(3), 1·88(6) and 1·56(7) eb for ^{194,196,198}Pt respectively. These numbers are weighted means of the previous model-independent results in Table 5. The results are shown in Table 6. As Fig. 3*b* shows, this analysis of the ^{196}Pt data gives a definite value for $\langle 0_1^+ \| M(\mathrm{E4}) \| 4_1^+ \rangle$ rather than an upper limit because the previous measurements of $\langle 2_1^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle$ for this nucleus are both smaller than the value quoted in Table 3. The value obtained for $Q(4_1^+)$ of ^{194}Pt is sensitive to the value of the matrix element $\langle 2_2^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle$, which is unknown. Despite this and the large uncertainties, positive quadrupole moments are clearly favoured for the 4_1^+ states of these nuclei.

Table 6. Values of $\langle 0_1^+ \| M(\mathrm{E4}) \| 4_1^+ \rangle$ and $Q(4_1^+)$ obtained from the present work using previously measured values of $\langle 2_1^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle$

Nucleus	$\langle 2_2^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle = 0$		$\langle 2_2^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle = 0{\cdot}5\ e\mathrm{b}$	
	$\langle 0_1^+ \| M(\mathrm{E4}) \| 4_1^+ \rangle$ ($e\mathrm{b}^2$)	$Q(4_1^+)$ ($e\mathrm{b}$)	$\langle 0_1^+ \| M(\mathrm{E4}) \| 4_1^+ \rangle$ ($e\mathrm{b}^2$)	$Q(4_1^+)$ ($e\mathrm{b}$)
^{194}Pt	−0·25(7)	0·7 (6)	−0·24(7)	0·2 (6)
^{196}Pt	−0·19(7)	2·5(1·1)	−0·19(7)	2·3(1·1)
^{198}Pt	−0·09(9)	1·3(1·8)	−0·09(9)	1·4(1·8)

Table 7. Theoretical predictions of the deformation parameters β_2 and β_4 of ^{194}Pt compared with those extracted from the present data using the rigid rotational model

β_2	β_4	Reference
0·11	0·04	Nilsson *et al.* (1969)
−0·16	−0·04	Götz *et al.* (1972)
0·09	0·03	Ragnarsson *et al.* (1974)
0·23	0·17	Nerlo-Pomorska (1979)
$-0{\cdot}17 < \beta_2 < -0{\cdot}11$	$0 < \beta_4 < 0{\cdot}05$	Bengtsson *et al.* (1984)
−0·13	−0·01	Ansari (1986)
−0·15	−0·08	Present work

It is interesting to apply the rotational model to the results in Table 3 to obtain values of the deformation parameters β_2 and β_4. By starting from the general expression for the multipole operator in collective coordinates (Eisenberg and Greiner 1978) and assuming a rigid, axially symmetric shape, one finds

$$\langle I' \| M(\mathrm{E}\lambda) \| I \rangle = (-)^\lambda (2I'+1)^{\frac{1}{2}} C(I'\lambda I;\, 000)\, 3ZeR_0^\lambda f_\lambda / 4\pi\,, \tag{5}$$

where $C(abc;\, \alpha\beta\gamma)$ is a Clebsch–Gordan coefficient and Z and R_0 are the atomic number and mean radius of the nucleus. If one restricts the deformation to the quadrupole and hexadecapole only, then, to second order in the deformation parameters,

$$f_2 = \beta_2 + 2(5\pi)^{\frac{1}{2}}\beta_2^2/7\pi + 12(\pi)^{\frac{1}{2}}\beta_2\beta_4/7\pi + 20(5\pi)^{\frac{1}{2}}\beta_4^2/77\pi\,, \tag{6}$$

$$f_4 = \beta_4 + 9(\pi)^{\frac{1}{2}}\beta_2^2/7\pi + 60(5\pi)^{\frac{1}{2}}\beta_2\beta_4/77\pi + 729(\pi)^{\frac{1}{2}}\beta_4^2/1001\pi\,. \tag{7}$$

For ^{194}Pt, we have $\langle 0_1^+ \| M(\mathrm{E2}) \| 2_1^+ \rangle = 1{\cdot}289\ e\mathrm{b}$ (Gyapong *et al.* 1986) and, from Table 3, $\langle 0_1^+ \| M(\mathrm{E4}) \| 4_1^+ \rangle = -0{\cdot}23\ e\mathrm{b}^2$. These give $\beta_2 = -0{\cdot}153$ and $\beta_4 = -0{\cdot}076$. There have been many calculations of β_2 and β_4 for ^{194}Pt; some of these are compared with the experimental values in Table 7. [Several of the references listed in Table 7 report values of ϵ and ϵ_4; these were converted to β_2 and β_4 using Fig. 9 of Nilsson *et al.* (1969).] Comparisons of the sort presented in Table 7 have been criticised (Nazarewicz and Rozmej 1981) on the grounds that the use of the rigid rotational model to relate matrix elements to β_2 and β_4 and the exclusion of all other degrees of freedom are very severe approximations. Nevertheless, it is interesting that several calculations have failed to obtain the correct sign of β_2. The calculations of Götz *et al.* (1972) give results close to our values.

5. Conclusions

From measurements of the Coulomb-excitation probabilities of the 4_1^+ states of ^{194,196,198}Pt we obtain model-independent values of the magnitudes of $\langle 0_1^+ \| M(\mathrm{E4}) \| 4_1^+ \rangle$ and $\langle 2_1^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle$. Their signs are adopted from previous work. Our values of $\langle 2_1^+ \| M(\mathrm{E2}) \| 4_1^+ \rangle$ are in reasonable agreement with values from other model-independent measurements. If we incorporate these other measurements into our analysis, then we can extract values of $Q(4_1^+)$. Although the uncertainties on these values are large, the results indicate that $Q(4_1^+)$ is positive for all of these nuclei, that is, that $Q(4_1^+)$ has the same sign as $Q(2_1^+)$. Application of the axially-symmetric rigid-rotor model to the measured values of $\langle 0_1^+ \| M(\mathrm{E2}) \| 2_1^+ \rangle$ and $\langle 0_1^+ \| M(\mathrm{E4}) \| 4_1^+ \rangle$ for ^{194}Pt suggests that both β_2 and β_4 are negative for this nucleus. Not all calculations of these quantities have obtained this result.

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